Nova Note 701, Version 2

Creep rate versus Stress

Hans Jostlein 3/28/2006

Abstract

We show new creep data on PetB. (we correct a numerical factor that was used in calculating creep strain) .

To facilitate comparison to the recent report on PVC creep provided by Ray Harrell to ANL(and posted at the nova DocDB as note # 667) , we show our PETB data for 65 days expressed as a creep modulus. The existence of a single "creep modulus", independent of stress, is not supported by our creep data.

We find that extrapolation to 20 years is difficult.

We provide additional comments on the viscoelastic analysis used by Mr. Harrell.

Initial concerns are:

The theory is valid only "near and above the glass transition temperature"

The theory takes data taken "over 3 decades of frequency" and extends them to "15 decades by the FTS method"

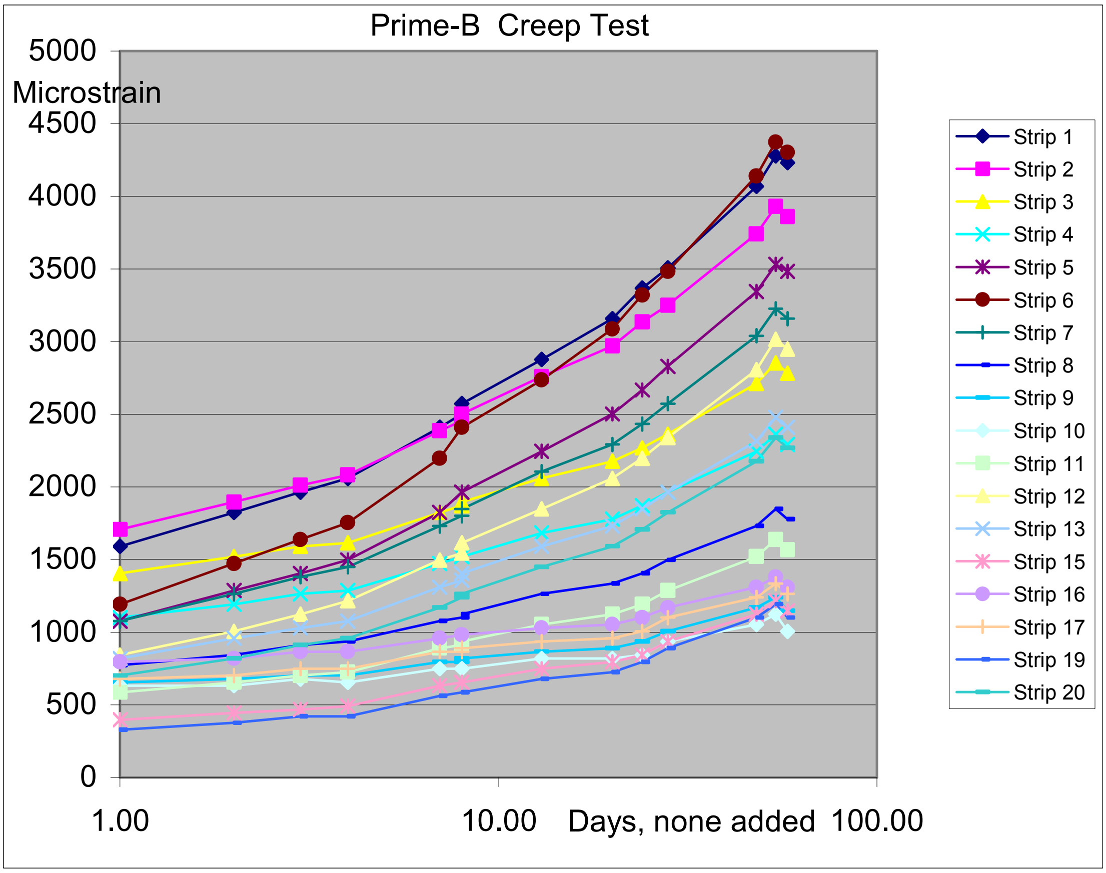
The derived density (Fig.6) dependence is completely wrong. The author fixes that by setting beta=zero.

The piece-wise assembly of the master curve (Fig 7) from shifted data is less than convincing. Every instance of the input data is in significant shape disagreement with the master curve.

I will refer to the book "Viscoelastic Properties of Polymers" by John Ferry that is the basis of the viscoelastic analysis used by Mr.Harrell.

Creep Data for PetB for 65 days

We have measure creep for 18 samples at room temperature.
The strain versus time is displayed in the following figure:

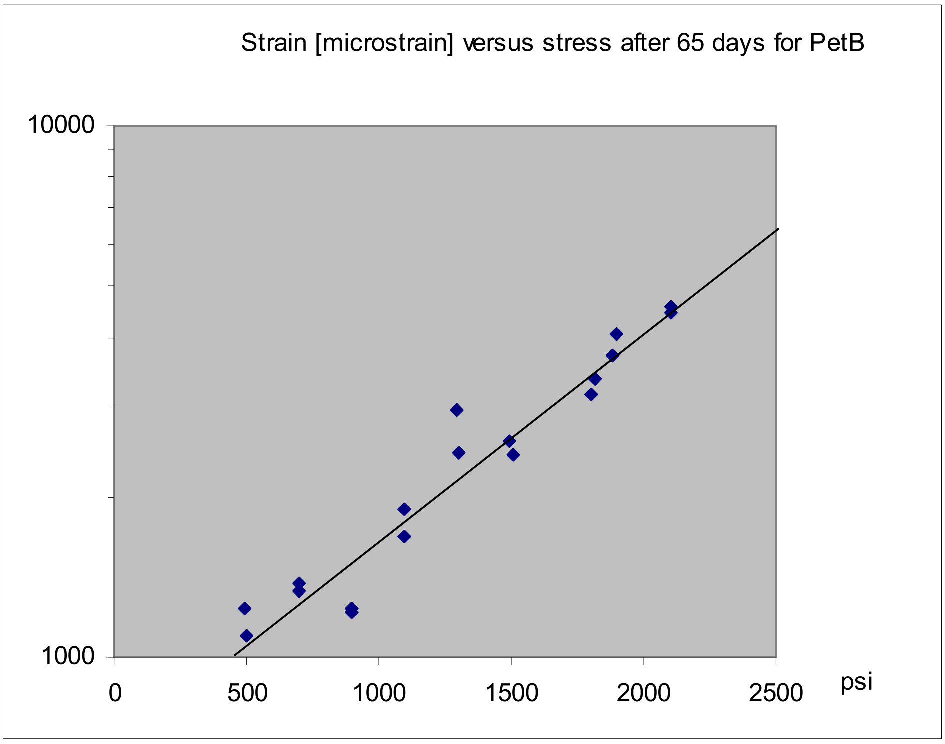


The stresses [psi] on each strip are:

Strip #	1	2	3	4	5	6
Stress	2100	1900	1297	1299	1882	2101
Strip #	7	8	9	10	11	12
Stress	1814	1097	496	497	1098	1803
Strip #	13	15	16	17	19	20
Stress	1492	898	698	698	899	1504

We see the typical flatter start at early times, followed by a later rise that is consistent (but not proven to be) of logarithmic form , which would be a straight line on this graph. The early flat part is an artifact of plotting against the log of time; at short times the dependence must change due to the divergence of the log function.

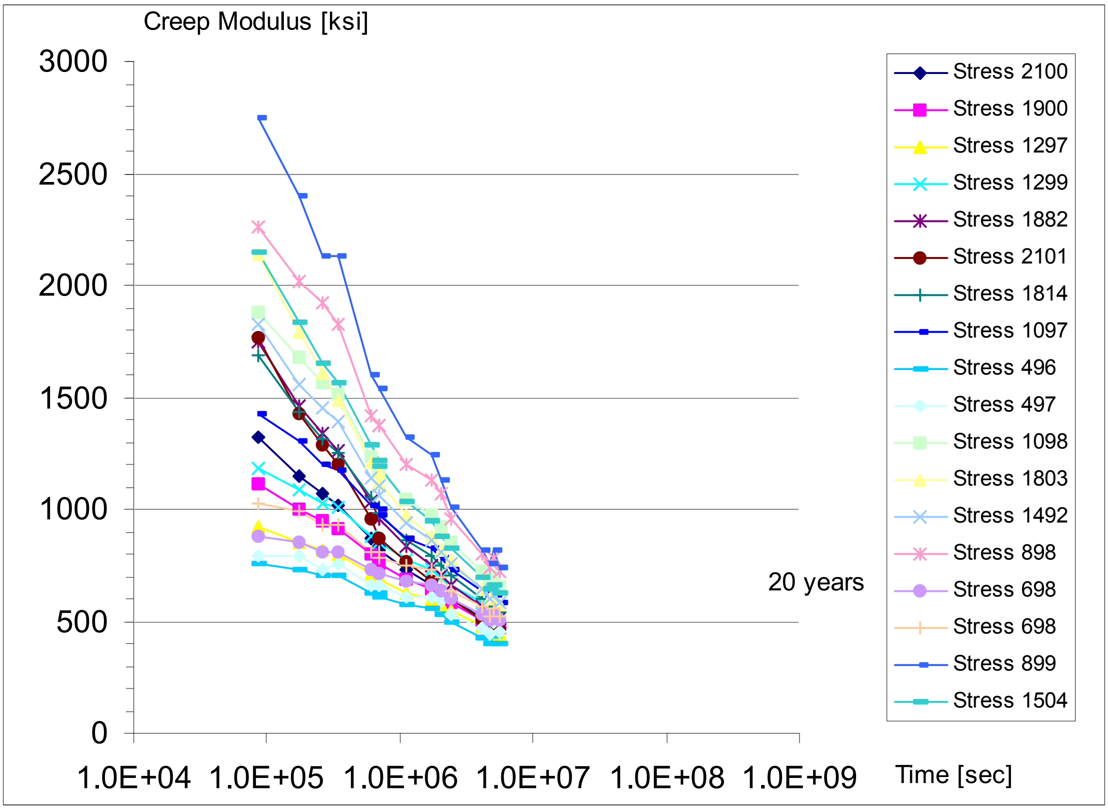
Strain versus stress for PetB after 65 days



The strain after 65 days for PetB appears to grow exponentially with stress.

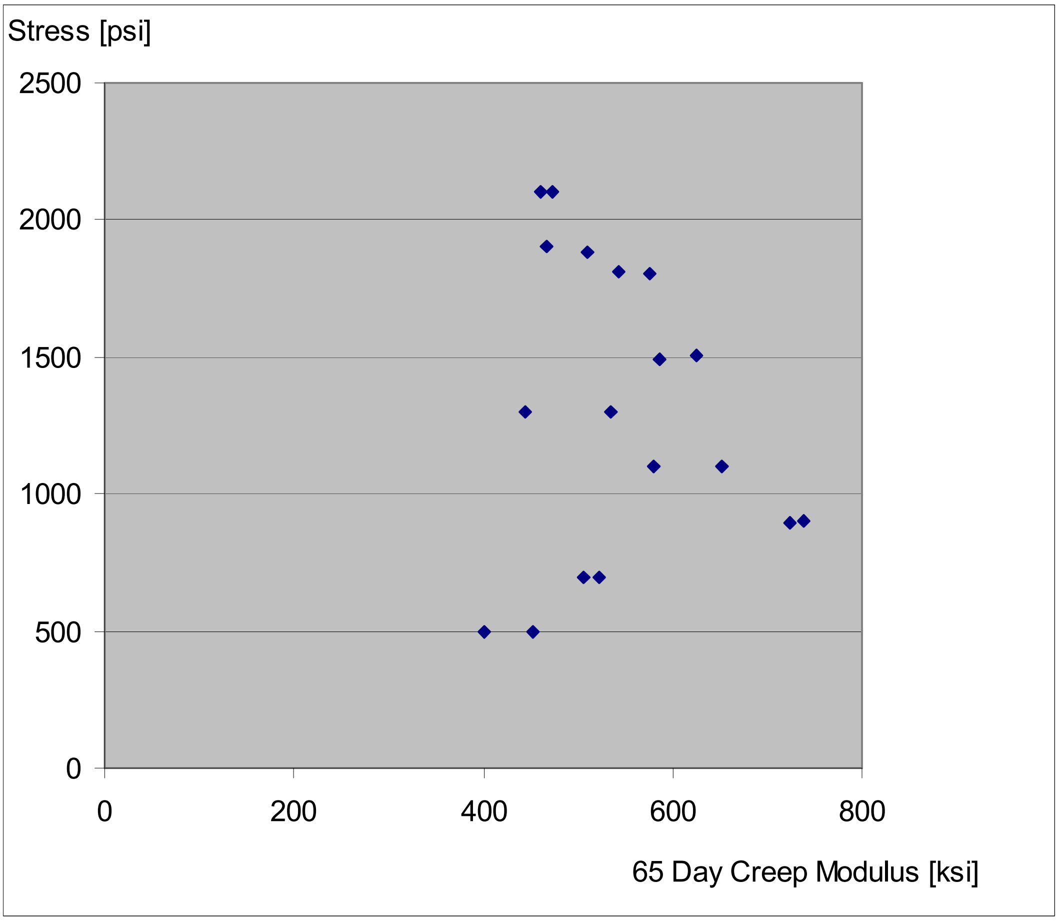
PetB Creep plotted as a "Creep Modulus"

To facilitate comparisons to the Farrell report, we present here the same data expressed as a "Creep Modulus", defined as(Creep stress / creep strain) as a function of time. Note that my earlier report had an error. The present data are correct as far as I know.



This graph of Creep Modulus versus log(time) shows a number of things:

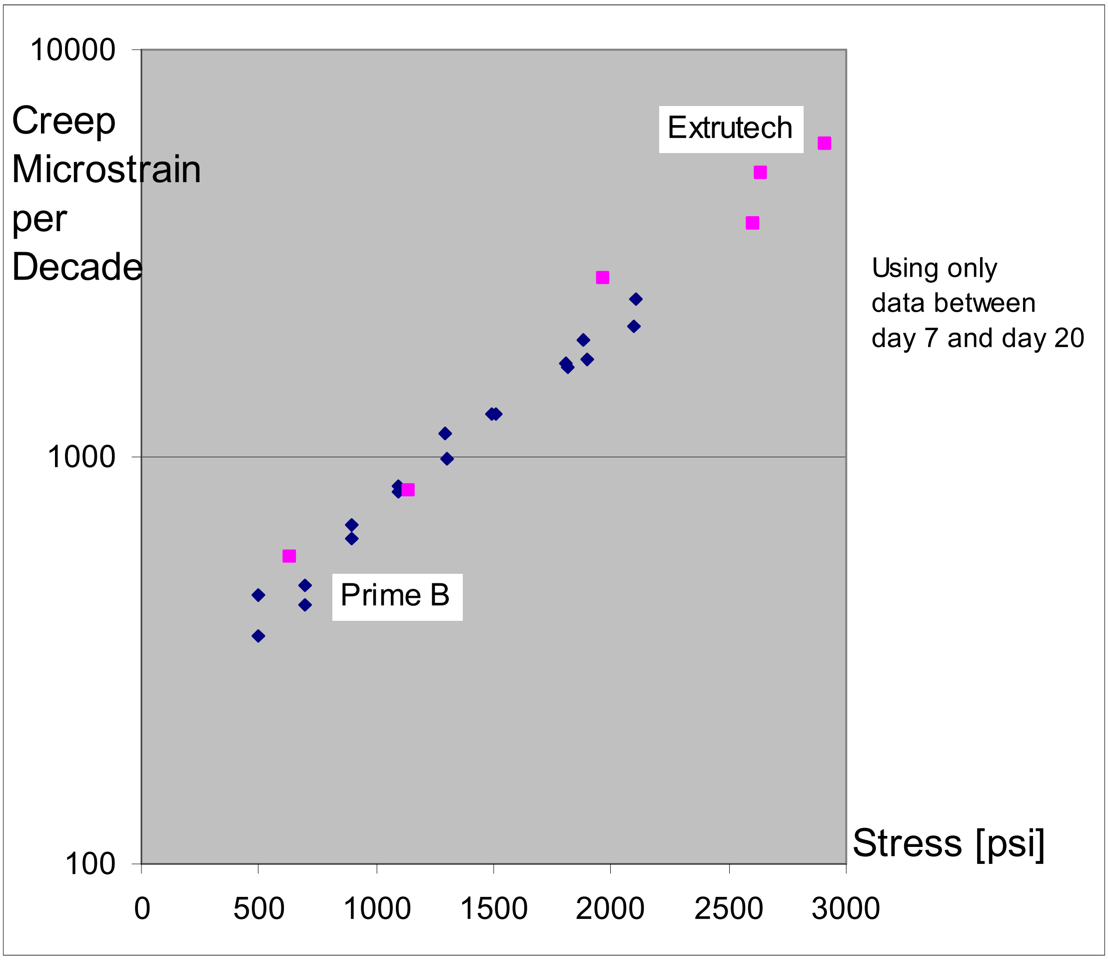
a. The creep modulus starts out very different for different stresses, being highest for the lowest stresses
b. The Creep modulus is steeper for lower stresses, hence its value is less dependent on stress as time goes on. See the following graph of stress vs. Modulus at 65 days (sorry for the exchanged axes)
c. The Creep modulus may be proportional to log time
d. The 20 year point is marked on the graph.
There appears to be no plausible way to extrapolate to 20 years. Since PVC pipes do not collapse after 20 years, it is reasonable to assume that the curves must flatten as time gets very long.



The Creep Modulus" for PetB after 65 days is not a clear function of Stress.
This graph is the same as the "Strain versus Stress " at 65 days (shown above), except that the strain values are now divided by the stress. This removes most of the slope in the earlier graph, and we are left with the measurement errors (and thermal expansion) effects.

Creep Comparison of Extrutech with PetB

We plot the slope creep strain [micro strain per decade] versus stress for the two materials:



We note that the creep properties of the two materials are very similar. Maybe the longer-term Extrutech data can guide us as to what we should expect from PetB ?

Additional Comments on the Visco-Elastic Analysis

I have looked some more (but not read the whole thing) into the Ferry book.
The analysis is appropriate for materials that behave like visco-elastic solids of visco-elastic fluids.
The premise is that such materials can be modeled as a series of springs and viscous dashpots. Each spring / dashpot combination has a characteristic frequency (or response time) given by its decay time constant. An ensemble of these elements are thought to be able to model pretty much any material.
At the introduction of the spring models ("Maxwell" with parallel springs and " Voigt" with springs in series), the author cautions that "If appropriate values for G and Tau (or eta) (which are the spring and dashpot parameters) are assigned, in principle all the viscoelastic functions can be calculated by formulas given in Chapter 3. In practice, such a procedure is rarely attempted, except for rough calculations. The chief value of the model is a guide for qualitative thinking"

It is immediately clear by inspection of the model that measurements over a given time or frequency range are sensitive only to those spring/dashpot elements that have characteristic times or frequencies in the measurement range. Faster and slower elements do not contribute to the observations, hence cannot be measured.
If one naively extrapolates the measured parameters, that is equivalent to assuming that there exist no elements with frequencies or time constants outside of the range of measurements.
This is an absurd assumption.
The assumption is, in fact invalidated later in the book, e.g. in chapter 3, after equations 36 through 39.
The author states:
"In practice the functional forms of G* and J* are so complicated, as seen in Chapter 2, that usually no attempt is made to represent them by analytical expressions , and the data remain in tabular or graphical form. Even if they were fitted by an empirical equation within the range of experiments, it would not be certain that the equation would have the analytical continuation outside the range which the calculation implies. Thus equations 6 to 39 are rarely used for experimental data"

How can we get a Handle on Long Term Creep?

The obvious method would be, of course, to measure creep over very long times.
This has practical limits, since 20 years are not available.
We saw earlier that extrapolation of the modulus leads to an implausible result, i.e. modulus about zero at 20 years.
One can, instead, assume that the creep strain is proportional to log(time) and get some estimate, but without much theoretical foundation.
Other avenues to explore are to run long-term (few months) creep tests at various temperatures, and then extrapolate to room temperature. This method can arguably make sense in that long time observations are combined with "accelerated time", i.e. elevated temperature.
Clearly this merits further discussion.
We may even just start such a program while we try to sort out the theory.

Comments are welcome.